METHOD AND SYSTEM FOR NON-INVASIVE MEASUREMENT OF PRESCRIBED CHARACTERISTICS OF A SUBJECT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and system for the non-invasive measurement of health signs or prescribed characteristics of a subject.

2. Description of Related Art

Remote monitoring of prescribed characteristics of a subject, such as temperature, breathing and heart activity, can be useful for many applications where the knowledge of a subject's current medical condition or interactive responses is needed, but direct interaction with, for example, a physician or monitoring system is not possible. This is particularly useful for outpatients with conditions that require vigilant observation. Monitoring such patients remotely can significantly reduce the cost and difficulty associated with frequent hospital visits.

Currently available outpatient monitoring systems involve the use of bulky and costly instruments that the patient or an assistant must administer in order to retrieve medical data. Thus, this procedure can only be performed at a fixed location (such as a doctor's office or the patient's home), when convenient. Some other types of smaller, more portable monitoring devices have been implemented for tracking and monitoring prescribed characteristics in various applications such as wildlife studies. These applications typically involve the attachment of an active electronic circuit to the subject, that can download recorded data, or transmit data to a remote receiver in real-time. Miniaturization and life span of these circuits is usually limited by the need for an internal battery, and telemetry of data usually requires that a transponder be administered to the device, or that the device radiate energy.

Accordingly, a demand exists for a more flexible monitoring system, which would allow the monitoring of subjects without undue restrictions on those subjects.

SUMMARY OF THE INVENTION

The non-invasive measuring system and method according to the present invention uses, in one embodiment, a wireless communication device having an independent wireless communication function to make the measurements. The wireless communication function of this device is then used to provide the measurements to a, potentially remotely located, presentation device. In so providing the prescribed characteristic measurements, the existing communication network infrastructure is, preferably, used to convey the measurements.

In other embodiments, devices having functionality other than as prescribed characteristic sensing devices, such as a motion sensor, include the additional function of being able to make prescribed characteristic measurements.

As a result, the present invention removes the restrictions conventional measuring systems impose on monitored subjects. Accordingly, great flexibility is achieved in making measurements according to the method of the present invention.

In further embodiments, placing a body sensor on the target subject enhances the return of the signal reflected from the subject and/or additional information is modulated onto the return signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, wherein like reference numerals designate corresponding parts in the various drawings, and wherein:

Fig. 1 illustrates various non-invasive measurement systems according to the present invention;

Fig. 2 illustrates one embodiment of a modified wireless phone architecture for performing the measurement function according to the present invention;

Fig. 3 illustrates another embodiment of a modified wireless phone architecture for performing the measurement function according to the present invention;

Fig. 4 illustrates still another embodiment of a modified wireless phone architecture for performing the measurement function according to the present invention;

Fig. 5 illustrates a conventional wireless LAN adapter;

Fig. 6 illustrates a wireless LAN adapter according to the present invention operating in a measuring mode;

Fig. 7 illustrates an embodiment of a motion sensor modified to serve as a sensing device according to the present invention;

Fig. 8 illustrates one embodiment of the presentation device including filters according to the present invention;

Fig. 9 illustrates the oscilloscope output for several waveforms generated according to the present invention;

Fig. 10 illustrates a reflective sensor according to the present invention;

Fig. 11 illustrates an example of a body sensor incorporating reactive loading to modulate electrical length according to the present invention;

Fig. 12 illustrates a resonant circuit body sensor according to the present invention;

Fig. 13 illustrates a multiplying body sensor according to the present invention;

Fig. 14A illustrates a resonant type body sensor to delay and modulate the return signal according to the present invention;

Fig. 14B illustrates simulated incident and return signals for the body sensor of Fig. 14A; and

Fig. 15 illustrates a simple active DC powered body sensor according to the present invention.

DETAILED DESCRIPTION OF THE PREFFERED EMBODIMENTS

Fig. 1 illustrates various non-invasive measurement systems according to the present invention. As shown, the prescribed or predetermined characteristics (e.g., temperature, breathing activity, heart activity, etc.) of a subject 2 are measured in a non-invasive manner

using one or more wireless communication devices 10 such as a wireless phone 12, a wireless local area network (LAN) adapter 14 and a cordless phone 16. Alternatively, the non-invasive measurements are made using one or more wireless sensor devices 20 such as a motion sensor 22. While the subject 2 has been illustrated as a human being in Fig. 1, it will be understood that the subject 2 is not limited to human beings.

The measurements are communicated to a, potentially remotely located, (e.g., a doctor's office), presentation device 30 via a communication network 40. For the wireless phone 12, the communication network 40 includes a wireless communication infra-structure 42, (e.g., base stations, mobile switching centers, etc.), necessary to connect wireless phones and the internet and/or public switched telephone network. Hereinafter, and as shown in Fig. 1, the internet and/or public switched telephone network is collectively referred to as IP Network 44. For the wireless LAN adapter 14, the cordless phone 16 and the motion sensor 22, the communication network 40 includes the IP network 44.

As discussed in more detail below, using the transmission and/or reception capabilities of wireless communication devices 10 and other wireless sensor devices 20, these capabilities existing for the purposes other than measuring prescribed characteristics, prescribed characteristics of a subject 2 can be measured in a non-invasive manner. And, using the communication infrastructure associated with devices 10 and 20, the measurements can be communicated to a destination device. Furthermore, the system according to the present invention also makes use of the existing non-associated communication infra-structure in transferring the measurement data to the presentation device 30.

Next, measuring prescribed characteristics of a subject using each of the illustrated devices will be discussed in detail below, followed by a detailed description of the presentation device.

Wireless and Cordless Phones

As is known, wireless phones transmit and receive signals at respectively different frequencies using a single antenna and known frequency-duplex techniques. The existing

wireless phone architecture does not necessarily permit transmission and reception of same frequency signals using a signal antenna; consequently, some modifications or additional components are needed to perform the measurement function.

Fig. 2 illustrates one embodiment of a modified wireless phone architecture for performing the measurement function according to the present invention. As shown, the existing wireless phone architecture 50 is connected to one terminal of a three terminal circulator 52. An antenna 54 and a mixer 56 are connected to the other two terminals of the circulator 52, and a coupler 58 couples the output of the wireless phone architecture to the mixer 56. The output of the mixer 56 is supplied to the wireless phone architecture.

The existing wireless phone architecture 50 is pre-programmed to transmit a signal using the transmission capabilities thereof for the purposes of making measurements. As one skilled in the art will appreciate, pre-programming the wireless phone architecture 50 in this manner permits great flexibility in the timing of the measurements. For instance, measurement could be made on a periodic basis, and the results stored and transmitted when the wireless phone 12 is not in use. Accordingly, the timing of transferring the accumulated measurements may also be controlled a priori through the programmed architecture 50. The program, additionally or alternatively, permits measurements on demand, by allowing an operator to request the making of a measurement through key input.

Acting as a signal source, the architecture 50 supplies a signal to the circulator 52, which is provided thereby to the antenna 54. The transmitted signal reflects from the subject 2, and is received by the antenna 54. The circulator 52 supplies the received signal to the mixer 56, which mixes the received signal with the transmitted signal to obtain a difference signal, which is proportional to target motion (e.g., heart, lungs, chest, etc.).

Namely, the output of the mixer 56 is the prescribed characteristic measurement, and this measurement is temporarily stored in the memory of the architecture 50. By providing greater storage capacity in the existing architecture 50, the number of stored measurements could be increased and the time between transmitting the measurements could likewise be increased.

According to the programming, the architecture 50 places a call to a pre-programmed number and delivers the measurements. Namely, based on the pre-programmed number, the wireless communication infra-structure 42 receives and routes the measurements to the presentation device 30 via the IP network 44.

Fig. 3 illustrates another embodiment of a modified wireless phone architecture for performing the measurement function according to the present invention. As shown, an auxiliary receiver module 60 is connected to a wireless phone 62. Some existing wireless phones already permit the attachment of modules, such as infrared LAN units, and these existing attachment features are used to attach the auxiliary receiver module 60.

The auxiliary receiver module 60 includes an antenna and receiver circuitry for receiving the signals transmitted by the wireless phone 62, which have reflected off of the subject 2. The auxiliary receiver module 60 sends the received signals to the wireless phone 62 for mixing with the transmitted signal and for transmission of the resulting difference signal to the presentation device 30 as discussed above with respect to Fig. 2.

Fig. 4 illustrates another embodiment of a modified wireless phone architecture for performing the measurement function according to the present invention. As shown, an auxiliary transponder module 64 is connected to a wireless phone 62. The auxiliary transponder module 64 both transmits signals for measurement of prescribed characteristics and receives the reflection of the transmitted signals. The transponder module 64 may have the same structure as the wireless LAN adapter 14 and the motion sensor 22 discussed in detail below. Alternatively, the transponder module 64 could be any conventional non-invasive measurement device adapted for connection to the wireless phone 62. As with the embodiment of Fig. 2, the transponder module 64 sends the received signals to the wireless phone 62 for transmission to the presentation device 30 as discussed above with respect to Fig. 2.

Cordless phones, albeit operating at different frequencies than wireless phones, operate in an analogous manner; wherein the handset of the cordless phone can be viewed as the wireless phone, and the base of the cordless phone, in wireless communication with the handset, can be viewed as the base station in wireless communication with the wireless

phone. To that end, a cordless phone can be modified in the same manner as described above with respect to wireless phones to perform non-invasive measuring. The measurements are then communicated to the presentation device 30 via the base of the cordless phone and the IP network 44, to which the base is connected.

Additionally, however, because of the relative close proximity to the subject 2, the base of the cordless phone could also be modified as discussed above with respect to wireless phones to make non-invasive measurements. The base, then, conveys the measurement data to the presentation device 30 over the IP network 44.

In a further alternative embodiment, the transmission and reception functions could be divided between the base and handset.

Wireless LAN Adapters

A wireless LAN adapter replaces the wired computer link (e.g., Ethernet) with a wireless link. As with wireless phones, wireless LAN adapters have built-in carrier wave sources that, in the present invention, are used to provide the measurement interrogation signal. For those wireless LAN adapters operating in the same frequency duplex manner as wireless phones, the same modifications discussed above with respect to wireless phones would allow implementing those wireless LAN adapters in the system of the present invention.

Some wireless LAN adapters like Lucent Technologies' WaveLAN card use a time-duplex system, which means that a signal can not be simultaneously transmitted and received. However, the WaveLAN card employs two antennas in a diversity system as shown in Fig. 5. Namely, as shown in Fig. 5, the WaveLAN card 70 includes first and second antennas 72 and 74 connected to a diversity system 76. The input/output of the diversity system 76 is connected to a transmit/receive (T/R) switch 78, and the transmitter/receiver architecture 80 is connected to the T/R switch 78. When transmitting, the T/R switch 78 connects the transmitter portion of the transmitter/receiver architecture 80 with the antenna 72 through the diversity switching system 76. When receiving, the T/R

switch 78 connects the receiver portion of the transmitter/receiver architecture 80 with the antennas 72 and 74 through the diversity switching system 76.

Through software or hardware modifications, the antennas operate as separate transmit and receive antennas for performing transmission and reception simultaneously during the non-invasive measuring as shown in Fig. 6. Specifically, in the modified WaveLAN card according to one embodiment of the present invention, the T/R switch 78 is redesigned to operate in a non-invasive measuring mode such that, as shown in Fig. 6, the transmitter and receiver portions of the transmitter/receiver architecture 80 are each connected to a respective one of the first and second antennas 72 and 74. Fig. 6 is conceptual block diagram of the wireless LAN adapter's operation in the measuring mode, consequently, the T/R switch 78 has been eliminated from the figure for the sake of clarity.

The wireless LAN adapter 14 is preprogrammed to perform non-invasive measuring and transfer of the measurements in the same manner as discussed above with respect to the wireless phone embodiments. The wireless LAN adapter 14 has communication capabilities associated with its function as a wireless LAN adapter. Using these capabilities, the wireless LAN adapter 14 transfers the measurements to the presentation device 30 over the IP network 44.

Additionally, as with cordless phones, a wireless LAN adapter includes a base in association therewith. Accordingly, the wireless LAN adapter can be viewed as the wireless phone, and the base, in wireless communication with the wireless LAN adapter, can be viewed as the base station in wireless communication with the wireless phone. To that end, a wireless LAN adapter can be modified in the same manner as described above with respect to wireless phones to perform non-invasive measuring. The measurements are then communicated to the presentation device 30 via the base and the IP network 44, to which the base is connected.

Also, because of the relative close proximity to the subject 2, the base could also be modified as discussed above with respect to wireless phones to make non-invasive measurements. The base, then conveys the measurement data to the presentation device 30 over the IP network 44.

In a further alternative embodiment, the transmission and reception functions could be divided between the base and wireless LAN adapter.

Sensing Devices

Sensing devices 20 such as motion sensors, (e.g., rf, microwave, and infra-red), while typically used for security purposes, are also well suited to making non-invasive measurements. In their conventional implementations, a controller performs a discrimination operation on the reflected signal to determine whether a subject is present. Based on the discrimination that a subject is present, an alarm is sounded, a door is opened, or etc.

By modifying the controller for the sensing device, the reflected signal is transferred over the IP network 44 to the presentation device 30. Fig. 7 illustrates an embodiment of a motion sensor 22 modified to serve as a sensing device according to the present invention. As shown, a motion detector 90 is connected to a controller 92. The motion detector 90 is the same as in conventional motion sensors. The controller 92 includes a transmitter/receiver controller 94 controlling the transmission of signals by the motion detector 90 and processing the received reflected signals for transfer of measurements over the IP network 44 by the communication network interface 96.

While the specific implementation of a motion sensor has been described, it should be understood that the present invention is not limited to motion sensors. Instead, any electromagnetic sensor (e.g. micro-impulse radar sensors) could be similarly modified to interface with the IP network 44 and provide measurements to the presentation device 30.

Operation and Analysis

Non-invasive measuring according to the present invention relies on the Doppler radar phenomenon, where the frequency of a radio signal is altered when the signal reflects off of a moving object. The periodic movement of the chest and internal organs modulates an incident or transmitted radio signal from one of the wireless communication devices 10 or the sensing devices 20, and the resulting reflection is interpreted to deduce, for example, heart and breathing activity. As discussed above, making non-invasive measurements can be

accomplished using a wide range of transmitter/receiver sets wherein preferred frequency ranges and power levels depend, in part, on the choice of the device 10 and 20. Since these devices already emit and receive radio signals in the presence of subjects, there is no need for additional licensing or regional regulatory approval.

The 900 MHz (cordless phone), 800 MHz (cell phone), 2.4 GHz (phone, LAN), etc. bands are well suited for this application. The penetration and resolution properties of a radio signal in this frequency range are adequate for monitoring heart and breathing activity through Doppler effects, and the allowed power levels are suitable for operation within reasonable proximity of the subject (body-contact through several meters displacement). The 10 GHz band commonly used for radio obstacle and motion detection, is similarly well suited for sensing, and if necessary its use can be combined with circuitry operating in a wireless communications band for additional flexibility in data transfer. At higher frequencies, around 24 GHz, higher resolution and improved antenna patterns could be used for more detailed observations of arterial motion. Significantly higher frequencies of operation (~30 GHz) are less common and signal penetration is reduced, but external surface motion could still be monitored for prescribed characteristics. At lower frequencies (<1 MHz), increased circuit size and a reduction in wavelength-dependent resolution could restrict applications.

The resulting mixed down received reflected signal (difference signal), i.e., the measurement data, is delivered via the communication network 40 to the presentation device 30. In its simplest form, the presentation device 30 is an oscilloscope displaying the waveform of the measurement data and/or a tone generator generating tones proportional to the data signal. In a more preferred embodiment, the presentation device 30 further includes a signal processor or filters, which operate to improve the displayed waveform and/or tone generation for a given characteristic.

Fig. 8 illustrates one embodiment of the presentation device 30 including filters according to the present invention. While the filters have been shown individually, it should be understood that the filtering could be performed in a signal processor. As shown, the signals representing the prescribed characteristics are filtered by a heart activity filter 100

and a respiration activity filter 102. The heart activity filter 100 is, for example, a bandpass filter passing 3-30Hz , and the respiration activity filter 102 is, for example, a bandpass filter passing 0.03-0.3Hz. An oscilloscope 104 displays the output of the heart and respiration activity filters 100 and 102. In alternate embodiments, the filters are included in the devices generating the measurement data.

Fig. 9 illustrates the oscilloscope output for several waveforms according to the present invention. The first waveform 110 is the raw baseband signal input to the heart and respiration activity filters 100 and 102. The second waveform 112 is the output of the respiration activity filter 102, and the third waveform 114 is the output of the heart activity filter 100. The fourth waveform 116 illustrates the output of an electrocardiogram (ECG) attached to the subject 2 having its prescribed characteristics measured in accordance with the present invention to provide a reference waveform for comparison. As shown in Fig. 9, the unfiltered, raw baseband signal alone provides understandable respiration and heart activity information to the trained eye, while the respective filtered waveforms can be interpreted by even the lay eye.

Enhanced Sensing Using Body Sensors

The non-invasive measuring techniques according to the present invention can be enhanced by the attachment of wireless sensors to critical locations on the body. The body sensor technique allows the return or reflected signal to be more easily isolated from radar clutter effects, and provides a means for sensing additional data not easily derived from a radar signal, such as skin temperature. The body sensors can be as simple as conductive patches that attach to the skin and enhance the reflection of the incident radio signal at a particular location. Alternatively, the body sensors are more complex frequency resonant structures, or even oscillating or multiplying semiconductor circuits. Such circuits can alter the reflected radio signal in time and/or frequency, and can impose additional modulated data, which is generated by, for example, skin temperature, bio-electric effects, re-radiated radar effects, and physical acceleration. More conventional signal generator circuits can also

be employed, which rectify the incident radio signal to provide a DC power supply. The body sensor can consist of single transponding elements or arrays of elements, and can be applied at a single or at multiple locations on the subject 2.

It is well known that a conducting surface will reflect most of the energy from an incident radio wave. Placing such a surface or patch on a target area of the body, such as the chest or the skin over an artery, will enhance the return of the radar signal from that target area. As one skilled in the art will appreciate, if the physical dimensions of the conducting surface are properly chosen, the path can act as an electrically resonant antenna that provides an enhanced radar return. Fig. 10 illustrates one example of such a reflective sensor. As shown, the body sensor is a conductive strip 120 having a length approximately equal to one-half the reflected wavelength and is placed perpendicular to the motion direction of the target area.

The electrical resonance of a body sensor such as illustrated in Fig. 10 can be controlled not only by the physical size, but also by reactive loading. By integrating variable reactive elements or electronic switching elements with the conductive patch, a body sensor, which effectively reflects radio waves and modulates the reflected signal with additional data, is obtained. Fig. 11 illustrates an example of a body sensor incorporating reactive loading to modulate the electrical length of the sensor. As shown, the body sensor includes the conductive strip 120 of Fig. 10 with switches 122 selectively connecting or disconnecting portions of the conductive strip. The switch 122 may be diode or microelectromechanical systems (MEMS) switches. The switches 122 open and close based on a control signal. Accordingly, the control signal modulates the return signal. By selecting a control signal representative of a prescribed characteristic, data on that characteristic can be modulated onto the return signal. Fig. 11 illustrates using the ECG (e.g., voltage difference between two points on the chest of the target subject as representative of the ECG), signal as the control signal to modulate heart rate data onto the return signal.

As a further alternative, shown in Fig. 12, an inductive antenna 130 is combined with a capacitive element 132, such as a diode varactor or MEMS varactor, to from a resonant LC circuit. In this body sensor, a control signal alters the capacitance of the capacitive element

132 to modulate the characteristic data represented by the control signal onto the return signal. Alternatively, a capacitive element 132 directly sensitive to a characteristic can be used. For instance, the capacitive element 132 could be a capacitor having a capacitance, which varies with temperature.

As previously mentioned, body sensors which isolate the incident signal from the return signal in time and/or frequency could also be used. One simple form of such a body sensor is a diode multiplier, which re-radiates harmonically related versions of the incident signal. Namely, this body sensor re-radiates a signal of frequency "f", at a new frequency of, for example, "2f". The return signal at frequency "2f" can be more easily isolated from the transmitted signal, for example, by using frequency-duplex techniques. Consequently, using body sensors of this nature would eliminate the need to modify the wireless communication devices to the extent necessary to receive same frequency transmit and receive signals using one antenna.

Fig. 13 illustrates one example of a multiplying body sensor. As shown, a first bandpass filter 140 filters the incident signal to pass the frequency "f", and a diode 142 operates to produce harmonics of the filtered signal. A second bandpass filter 144 filters the generated harmonic signals to pass the frequency "2f" as the return signal.

Another example of body sensor isolating the incident signal from the return signal in time and/or frequency is an oscillating sensor. An oscillating body sensor is energized by the incident signal, but re-radiates a new signal at a frequency controlled by the sensor. Such body sensors can also incorporate modulating components that superimpose additional information, as in the case of resonant reflector type sensors, on the return signal.

Fig. 14A illustrates one example of a resonant reflector type body sensor. As shown, this sensor is the same as the sensor illustrated in Fig. 12, except that (1) a tunnel diode 136 and second capacitive element 134 are connected across the first capacitive element 132 and (2), to the extent they are labeled in the drawing, first and second electrodes 138 and 139 are connected to each end of the first capacitive element 132. In this sensor, an incident pulsed radar signal, such as shown in the top half of Fig. 14B, couples to the inductive antenna 130, and rectification by the tunnel diode 136 charges the second capacitive element

134. When the incident pulse is absent, the second capacitive element 134 discharges, and the tunnel diode 136 oscillates at a frequency governed by the capacitance of the first capacitive element 132.

As discussed above, the capacitance of the first capacitive element 132 can be controlled or modulated in accordance with a prescribed characteristic, (e.g., temperature or motion), of the subject 2. In the body sensor of Fig. 14A, the first and second electrode 138 and 139 pick-up the ECG signal of the subject's heart, and the return signal is modulated via the first capacitive element 132 based on the ECG signal. Because the return signal is generated at times when the incident signal is absent, as shown in Fig. 14B, the desired return signal can be easily separated from the transmitted signal, and can reduce the amount of modification to devices 10 and 20 necessary to perform non-invasive measuring in accordance with the present invention.

Another type of body sensor is the fully active DC powered electronic circuit, which derives its power from an incident radio signal. Such a circuit produces its own appropriately bio-modulated signal communicated directly with a remote receiver or acts as a secondary radar source. Fig. 15 illustrates a simple example of this type of active DC powered body sensor. As shown, a rectifier 160 rectifies an incident signal received by an inductive antenna 162. The DC power generated by the rectifier powers an LC circuit 164, which generates a return signal having a frequency modulated by a prescribed characteristic in the same manner as in the body sensors of Fig. 12 and 14A.

Conclusions

Various implementations of the non-invasive measurement system according to the present invention are possible. For minimum interference and maximum resolution in measured parameters, like that desirable for heart signature, the device making the measurements can be applied directly to a specific area on the body, as in the case of a phone held on the chest. For more transparent monitoring the device can be kept at some non-specific distance from the body, as in the case of a desktop station. While this latter technique is more vulnerable to interference and signal degradation, it is adequate for less

critical measurements, such as heart rate. This latter technique also provides the benefit of acquiring data without imposing on the subject in a way that may alter the parameters being measured. This would be useful when the non-stressed state of the patient is of interest, or when the subject's response to some specific stimulus is required.

Additionally, the device generating the incident signal need not be the device processing the return signal. Instead, multiple coordinated devices could be used. But because the measuring devices can be embodied as part of a known device serving another purpose and subjects have become accustomed to keeping and using such devices, a subject will not experience any burden or undue restriction in the measurement process.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications are intended to be included within the scope of the following claims.

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